AD-A060 747 NAVAL RESEARCH LAB WASHINGTON D C F/G 17/9

DETERMINATION OF TARGET ALTITUDE WITH A TWO-DIMENSIONAL FREQUEN--ETC(U)

JUL 78 C L TEMES

UNCLASSIFIED NRL-8249 SBIE-AD-E000 221 NL

1 OF 1

AD
A060747

END
DATE
FILMED
01 -79
DDC

ADA060747

DDC FILE COPY

(12) LEVEL II

AD-E000221

NRL Report 8249

Determination of Target Altitude with a Two-Dimensional, Frequency-Agile Radar

C. L. TEMES

Search Radar Branch
Radar Division

July 31, 1978

NAVAL RESEARCH LABORATORY
Washington, D.C.

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. ~~REPORT NUMBER~~ (14) NRL ~~Report~~ 8249	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER (9)
4. TITLE (and Subtitle) (6) DETERMINATION OF TARGET ALTITUDE WITH A TWO-DIMENSIONAL FREQUENCY-AGILE RADAR,		5. ~~TYPE OF REPORT~~ & PERIOD COVERED Interim Report, on a continuing ~~NRL Problem~~
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) (10) Clifford L. Temes		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Naval Research Laboratory Washington, D. C. 20375		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS NRL Problem 53R12-52 Project S-0180-AA P. E. 63516N
11. CONTROLLING OFFICE NAME AND ADDRESS Naval Sea Systems Command Surveillance Systems Subgroup (652) Washington, D. C. 20360		12. ~~REPORT DATE~~ (11) 31 July ~~31~~, 1978
		13. ~~NUMBER OF PAGES~~ 12
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) (12) 12p.		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited (16) S0180

(17) S0180AA

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

(18) SBIE (19) AD-E000 221

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Altitude measurement
Radar
Frequency agility
Multipath lobing

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A technique is described for determining target altitude utilizing the frequency dependence of the multilobe antenna beam pattern resulting from sea reflections. A frequency-agile 2D radar is assumed.

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE
S/N 0102-014-6601

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

251 950

78 09 13 040 LB

CONTENTS

DETERMINATION OF TARGET ALTITUDE WITH A TWO-DIMENSIONAL, FREQUENCY-AGILE RADAR

INTRODUCTION

It would be useful if the altitude of target aircraft and/or missiles could be determined, even approximately, with a 2D air-search radar. The determination of altitude can expedite the handover from the 2D radar to a 3D or weapon-control radar. Not only would the latter have better information for localized elevation-angle search but, if the 2D radar is unstabilized, the altitude measurement can be used in conjunction with data from the ship's pitch/roll instrumentation to decrease the target azimuth measurement error due to vertical tilt of the 2D elevation fan beam. (See appendix for a more detailed discussion of this topic.)

The technique described here for determining target altitude is based on the frequency dependence of the multipath lobing structure and assumes a frequency-agile radar. Similar principles could be used, however, without frequency agility, but the altitude measurement would then be less accurate and would require more time. Frequency agility has also been considered for more accurate low-angle monopulse tracking,* but that application is substantially different from the one considered here.

BASIC RELATIONS DEFINING MULTIPATH LOBING STRUCTURE

Figure 1 shows a radar source at a height D/2 above an assumed ideal reflecting surface (water). The lobing structure is determined by the superposition of the direct and reflected rays; the latter can be assumed to be coming from an image of the source and to be 180° out of phase due to phase reversal on reflection.

If the direct ray at the target is represented by the complex signal,

$$\xi_d(t) = e^{j2\pi ft}, \tag{1}$$

the reflected ray is given by a delayed and phase-reversed version,

$$\xi_r(t) = e^{j2\pi f\left(t - \frac{D \sin \theta}{c}\right) - j\pi}, \tag{2}$$

where c = propagation velocity. The sum is

$$\xi(t) = \xi_d(t) + \xi_r(t) = e^{j2\pi ft}\left[1 + e^{-j\left(\frac{2\pi fD \sin \theta}{c} + \pi\right)}\right]. \tag{3}$$

---

*G. Linde, "Improved Low-Elevation Angle Tracking with Use of Frequency Agility," NRL Report 7378, March 17, 1972

Manuscript submitted June 14, 1978.

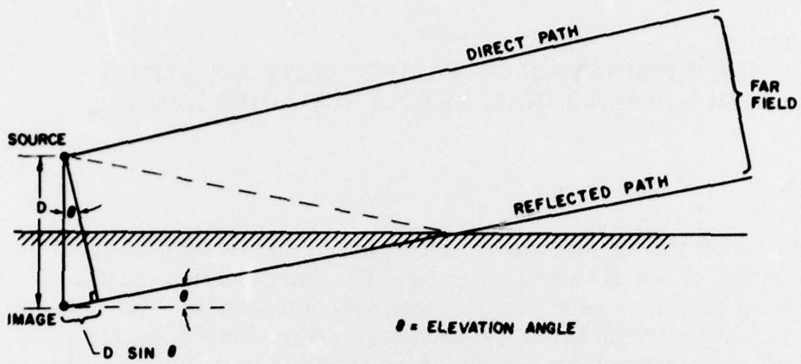

Fig. 1 — Geometry showing direct and reflected 2D radar signals

The magnitude can be determined by the formula

$$|\xi(t)| = -2 \sin\left(\frac{\pi D \sin\theta}{\lambda}\right), \tag{4}$$

where $\lambda = c/f$ = wavelength.

The round-trip voltage is proportional to

$$V(\theta) \propto |\xi(t)|^2 \propto \sin^2\left(\frac{\pi D \sin\theta}{\lambda}\right). \tag{5}$$

Nulls occur at the conditions

$$\frac{\pi D \sin\theta}{\lambda} = n\pi;\ n = 0, 1, 2, \ldots, \tag{6}$$

or when

$$\theta_N(n) = \arcsin\left(\frac{n\lambda}{D}\right);\ n = 0, 1, 2, \ldots \tag{7}$$

BASIC CONCEPT FOR MEASUREMENT OF TARGET ALTITUDE

To understand how the lobing structure and frequency agility can be used to determine target altitude, consider the example of a target flying radially inward at a constant 18.3 km (60 000 ft) altitude with a range rate of, say, 2000 ft/s = 0.329 n.mi./s. Assume that the target is detected at a range slightly beyond 150 n.mi. Such a trajectory is shown in Fig. 2. Let a 2D search radar be scanning at a 10 s period such that (for example) the target happens to be illuminated at a range of 150 n.mi., and every 10 s thereafter. Assuming, first, that we know true altitude and range at each scan through the target, from Fig. 2

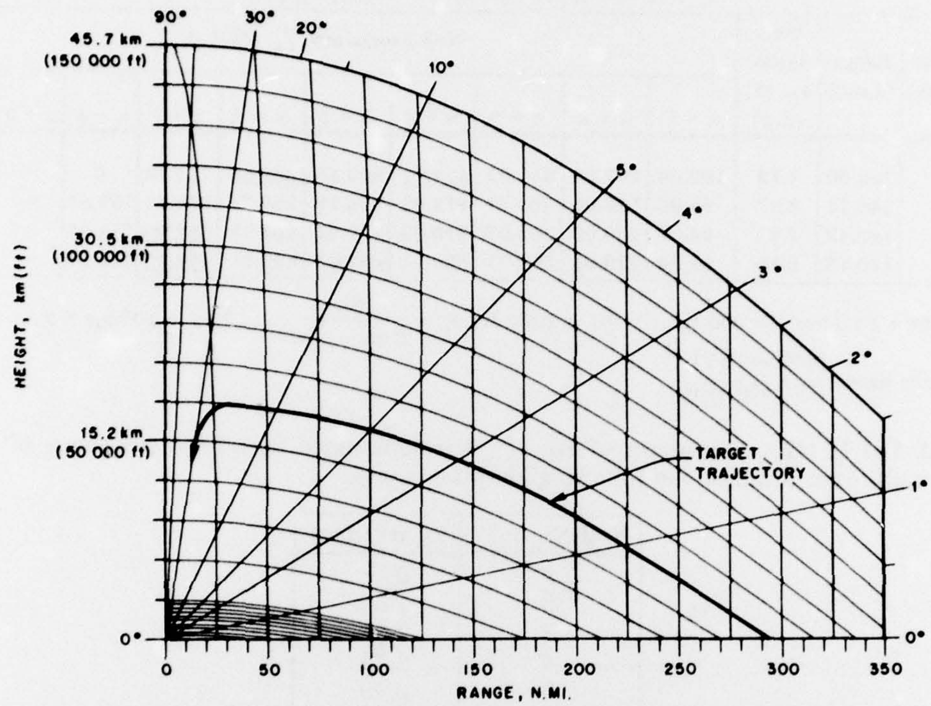

Fig. 2 — Geometry and assumed target trajectory

(or similar data) we can determine elevation angle at each dwell and thence, from Eq. (7), we can determine all frequencies which would result in a null being observed at each dwell. These results are shown in Table 1, where D = 61 m (200 ft). Certain frequencies are underlined to illustrate what would happen if we had a dual-band radar (for illustration) that was frequency agile in two simultaneous (10%) bands, say, 400-440 MHz and 600-660 MHz. As the radar beam sweeps past the estimated azimuth of the target, the pulses would be frequency-stepped during the dwell time. At a relative time of zero seconds, the lower band would estimate a null at 414.71 MHz and the upper band would estimate a null at 622.06 MHz. At a relative time of 10 s, neither band would find a null within its band, and so on.

In the above example, target altitude was assumed known to illustrate the principle. The following subsection shows how an unknown (constant) altitude could be determined.

ALGORITHM FOR DETERMINING AN UNKNOWN TARGET ALTITUDE

We assume a target on the same (but now unknown) trajectory as in the example in the preceding section. At a measured target range of 150 n.mi., the lower band detects a

Table 1 — Frequency, f_n, at Which Nulls Occur for Specified Elevation Angle, $\theta_N(n)$

Relative Time (s)	Range (n.mi.)	Elev. Angle, $\theta_N(n)$ (deg)	Null Frequency, f_n (MHz)									
			$n = 1$	$n = 2$	$n = 3$	$n = 4$	$n = 5$	$n = 6$	$n = 7$	$n = 8$	$n = 9$	$n = 10$
0	150.00	2.72	103.68	207.35	311.03	$\underline{414.71}$	518.38	$\underline{622.06}$	725.74	0	—	—
10	146.71	2.97	94.96	189.91	284.87	379.83	474.78	569.74	664.70	759.65	—	—
20	143.42	3.00	94.01	188.02	282.02	376.03	470.04	564.05	$\underline{658.06}$	752.06	—	—
30	140.13	3.15	89.54	179.07	268.61	358.14	447.68	537.21	$\underline{626.75}$	716.29	—	—

Altitude = 18.3 km (60 000 ft); D = 61 m (200 ft); $f_n = \dfrac{nc}{D \sin \theta_N(n)}$; $c = 2.99 \times 10^8$ m/s $= 9.84 \times 10^8$ ft/s;

frequency bands $\begin{cases} \text{400-440 MHz,} \\ \text{600-660 MHz.} \end{cases}$

null at 414.71 MHz. By means of Eq. (7), it is determined that, for a frequency of 414.71 MHz, nulls exist at all of the following elevation a[illegible]

Null No. (n)	$\theta_N(n)$ [illegible]
1	0.68
2	1.36
3	2.04
4	2.72
5	3.40
6	4.08
7	4.76
8	5.45
9	6.13
10	6.81
.	.
.	.
.	.

These angle lines are plotted in Fig. 3, where the intersection of these lines with the known (measured) range abscissa of 150 n.mi. gives a number of possible (ambiguous) altitudes of the target. We will assume there are seven feasible choices (up to 30.5 km altitude). This situation can be portrayed in a table such as Table 2, which shows the frequencies at which nulls would occur for each of the ambiguous altitudes. The underlined frequencies are those within the dual bands. Note that the 622.06 MHz null (mentioned in the preceding section) that would be observed in the upper band confirms (within some small assumed measurement error) that the altitudes 11.6 km (38 000 ft), 18.3 km (60 000 ft), and 24.7 km (81 000 ft) are real possibilities, whereas the others can be eliminated.

On the subsequent scan, the range has decreased to 146.71 n.mi., and there are three possible altitudes. Table 3 shows data similar to those of Table 1 for these three candidate altitudes. Note that nulls would be measured if the altitude were 24.7 km, but since such a null would not have been observed for the true altitude of 18.3 km, the 24.7 km candidate would be eliminated.

Table 2 — Possible Frequencies, f_n, for Specified Elevation Angles at Ambiguous Altitudes

Possible Altitude km and ft	Corresponding Elev. Angle, $\theta_N(n)$ (deg)	Possible Null Frequencies (MHz)											
		$n = 1$	$n = 2$	$n = 3$	$n = 4$	$n = 5$	$n = 6$	$n = 7$	$n = 8$	$n = 9$	$n = 10$	$n = 11$	$n = 12$
7.9 (26 000)	0.68	414.56	829.12										
11.6 (38 000)	1.36	207.30	414.59	621.89	829.18								
14.9 (49 000)	2.04	138.21	276.43	414.64	552.85	691.07	829.28						
18.3 (60 000)	2.72	103.68	207.35	311.03	414.71	518.38	622.06	725.74					
21.6 (71 000)	3.40	82.96	165.92	248.88	331.84	414.80	497.75	580.71	663.67	746.63			
24.7 (81 000)	4.08	69.15	138.30	207.45	276.60	345.75	414.90	484.05	553.20	622.35	691.50	760.65	
28.3 (93 000)	4.76	59.29	118.58	117.87	237.16	296.45	355.74	415.03	474.32	533.61	592.90	652.19	711.48

R = 150 n.mi.

Table 3 — Frequencies at Which Nulls Occur for Specified Range of 146.71 n.mi. and the Three Candidate Altitudes

Altitude km and ft	Elev. Angle (deg)	Null Frequencies (MHz)									
		$n = 1$	$n = 2$	$n = 3$	$n = 4$	$n = 5$	$n = 6$	$n = 7$	$n = 8$	$n = 9$	$n = 10$
11.6 (38 000)	1.50	187.95	375.90	563.85	751.81						
18.3 (60 000)	2.97	94.96	189.91	284.87	379.83	474.78	569.74	664.70	759.65		
24.7 (81 000)	4.19	67.34	134.68	202.01	269.35	336.69	404.03	471.37	538.70	606.04	673.38

R = 146.71 n.mi.; relative time = 10 s

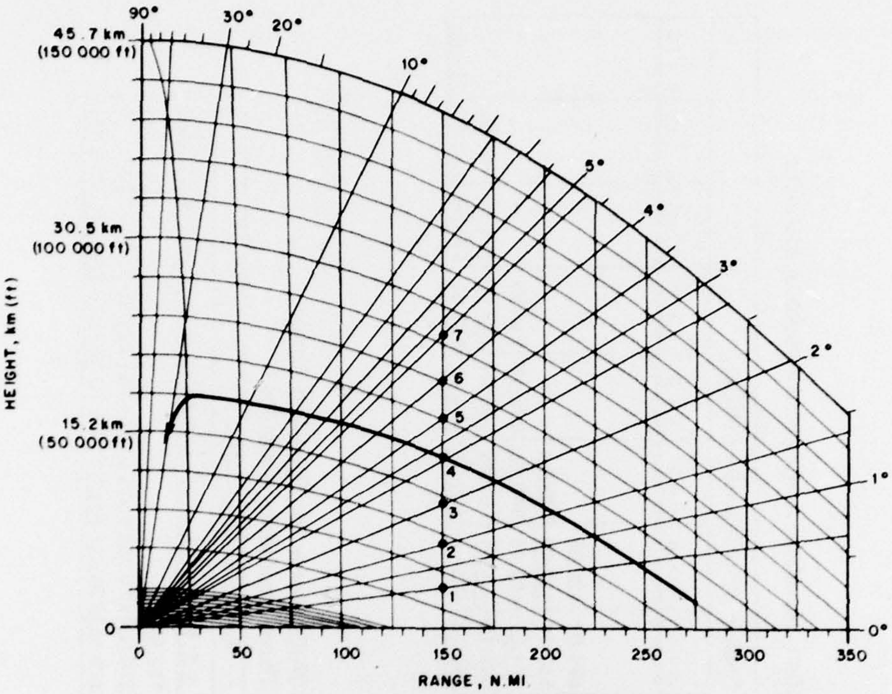

Fig. 3 — Ambiguous altitudes

Proceeding to the third scan at a relative time of 20 s, we now have two candidate altitudes at 11.6 km and 18.3 km; the range would be 143.42 n.mi. In the same format as Table 3, Table 4 shows the data for these new conditions. Since the radar would detect the null at 658.06 MHz, the 11.6 km altitude could be rejected, and target altitude after 20 s would thus be determined to be 18.3 km.

Table 4 — Frequencies at Which Nulls Occur for Specified Range of 143.42 n.mi. and the Remaining Two Candidate Altitudes

Altitude km and ft	Elev. Angle (deg)	Null Frequencies (MHz)							
		$n = 1$	$n = 2$	$n = 3$	$n = 4$	$n = 5$	$n = 6$	$n = 7$	$n = 8$
11.6 (38 000)	1.55	181.89	363.78	545.67	727.56				
18.3 (60 000)	3.00	94.01	188.02	282.02	376.03	470.04	564.05	658.06	752.06

R = 143.42 n.mi.; relative time = 20 s

CONCLUSION

Based on the example of a radar with frequency agility over 10% in each of two bands (400-440 MHz and 600-660 MHz), an algorithm was presented which conceptually

determined altitude in a sample case in about 20 s after detection of a first null at 150 n.mi. range. The scan period of the radar was assumed to be 10 s.

The objective of this report was to present the principle only, and no attempt was made to assess the effects of radar errors on the process described. Use of multipath nulls, as described here, presupposes that such nulls are well defined, which implies good forward scatter from the sea surface (low sea state, horizontal polarization, etc). Moreover, determination of null frequency positions from power-vs-frequency measurements has some associated difficulties; e.g.: (1) the frequency dependence of target radar cross section (due to multiple-scatterer interference) complicates the null-location process, (2) multipath effects from ship structure can cause difficulties, (3) the signal-to-noise ratio must be good for a well-defined, sharp null, (4) the implementation may be difficult due to the requirement for a fairly large number of frequencies over a wide band in a short time, particularly if clutter rejection is necessary.

Finally, all scenarios may not result in altitude determinations as quickly as that assumed in this report. Slower targets at low altitudes would present more of a problem.

ACKNOWLEDGMENTS

Helpful comments and discussions are acknowledged from the reviewers, Dr. R. J. Adams and Dr. B. H. Cantrell.

Appendix

CORRECTION OF AZIMUTH ERROR DUE TO FAN-BEAM TILT BY USING ALTITUDE INFORMATION

For illustration, let us assume a vertical surveillance fan beam directed normally away from the side of a ship; Fig. A1 shows the effect of pitch in rotating the beam off the vertical. The true target position and its image are as shown. Assume that an azimuth measurement is made by beam splitting or monopulse during an azimuth scan and that the beam tilt is known at that time from the ship's gyrocompass data. Also, for simplicity, since we are concentrating on beam-tilt errors alone, we assume here that errors due to noise are negligible.

The beam-tilt azimuth errors are due to several effects. First, if we assume negligible returns from the target image, the target azimuth will be estimated somewhere along the beam-elevation centerline, with the centerline passing through the true target position as indicated by Line A. In this case the addition of altitude information (as described in the body of this report) will help substantially in determining true target position. However, more realistically, the target image will cause the radar to estimate the position of a target centroid, as depicted in Fig. A-1. In this case, when the altitude information is applied, a false position estimate will be determined (to the left in Fig. A1). We can improve the azimuth measurement, which is subject to image corruption, by estimating the distance x between target altitude and centroid altitude on the basis of an estimated reflectivity of the ocean surface. For a tilt angle of θ, the measured target position should be moved to the right (in Fig. A1) by an amount determined by the formula $y = x \tan \theta$.

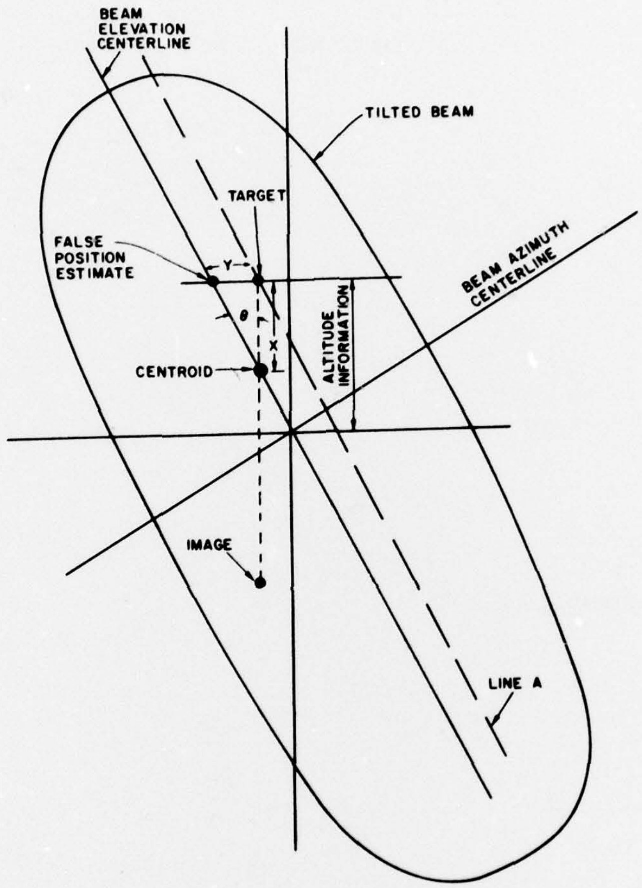

Fig. A1 — Errors due to fan-beam tilt